Xylem Dielectric Constant, Water Status, and Transpiration of Young Jack Pine (*Pinus banksiana* Lamb.) in the Southern Boreal Zone of Canada

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ABSTRACT

Diurnal changes of xylem dielectric constant (XDC), microclimate, and tree water status were studied in a young Jack Pine (*Pinus banksiana* Lamb.) stand in the southern boreal zone of Canada. Tree water status of trees was also manipulated by changing the canopy vapor pressure gradients in order to evaluate its influence on tree hydraulic conductance. Seasonal stand water consumption was calculated from tree transpiration, The mean XDC of eight concurrently monitored trees changed significantly from day- to nighttime. Individual trees varied widely in trend and diurnal amplitude of XDC changes. Correlation between individual tree's XDC, micro-meteorological parameters, tree water status and xylem flux was weak. Changes of XDC were observed during short term manipulation of water potential while tree water content did not change significantly. Xylem flux in trees was linearly related to the xylem water potential gradient. Tree hydraulic conductance was weakly correlated with xylem water potential and atmospheric vapor pressure deficit. No significant relationship was found between tree water potential and water content. Stand transpiration was depending on available soil water, reflected in a strong decreasing trend of transpiration vs. atmospheric vapor pressure differences during periods of water storage depletion.

INTRODUCTION

Implementation of radar remote sensing information of backscatter into ecophysiological models requires the description and evaluation of vegetation dielectric constant changes in respect to their influence on physiological vegetation parameters. In forests, the water status of trees may influence their dielectric properties and thus radar backscatter. This may result in detectable diurnal and seasonal changes of radar backscatter which are correlated to tree water status. We present here concurrent direct measurements of xylem dielectric constant (XDC) and tree water status parameters from a uniform atand of *Pinus banksiana*. We investigated diurnal and seasonal patterns of microclimate, tree sap flux, tree tissue temperature and tree XDC. In addition wc studied the effects of short term tree water status manipulation.

SITE DESCRIPTION

The experimental site is situated on an elevated plateau in 508 m a.s.l south of the Nipawin Provincial Park in N-Saskatchewan, Canada (53.875°N; 104.645''W). Surficial geology consists of plain glacio-lacustrine deposits with interspersed eolian dunes. Soils are weakly to noncalcareous sandy deposits, partly reworked by wind. Coarsely textured soils on hills have low water holding capacity and are well drained. The nearest meteorological station is Prince Albert (110 km SW) with a mean annual temperature of 0.5 "C (January mean daily min. -26.1 "C, abs. min. -50.0 "C, July: mean daily max. 24.2 'C, abs. max. 38.8 "C). Annual precipitation is 406 mm with 302 mm as rain and a max. of 72 mm in July [1]. The site is at the southern edge of the dry-continental boreal zone near the transition to the Aspen Parklands. Closed conifer forests reach their southern limit due to pronounced summer droughts. On well drained, dry, and nutrient poor sandy soils, even-aged, open stands of *P. banksiana* are dominant. Sparse understory is formed by *Arctostaphylos uva-ursi* and graminoids. Mature stands develop dense lichen covers of *Cladonia spp.* and *Pleurozium schreberi*. *The trees studied were in* an uniform atand of approx. *4* km^2 *(tree age* 11-16 years) on level ground. Canopy height varied from 4 to 6 m, canopy closure was 40 % (s.d. 18), with 2.19 treea m^{-2}. Basal area was 14.5 m* ha^{-1}, stand sapwood area was 1335 $mm^2\,m^{-2}$ (se. 133 mm^2, n=12). Understory was sparse with a lichen layer in its initial stage of development. Needle litter layer was 5 to 8 mm, soil carbon content decreased rapidly from 50 to 100 mm depth, and main roots ofP. *banksiana were* found to a depth of 100-350 mm.

METHODS

Microclimate, xylem sap flux density (XFD) and XDC were monitored continuously from Julian day (JD) 196-265 (15. July to 22. September 1994) with data stored in intervals of at least 30 min. Photosynthetic active radiation (PAR) was measured in 4.5 m height (LiCor). Canopy air temperature (TA) and relative air humidity (Campbell) were monitored at mid-canopy in 2.5 m and used to calculate the vapor pressure deficit (VPD). Soil temperature was measured in 50 mm depth and xylem (stern) temperature 0.6 m above the ground with thermistors (Siemens) inserted in 5 mm and 20 mm depth. XFD of nine trees was monitored in stems below the canopy at approx. 0.5 m height with a thermal constant energy input method [2]. Xylem water potential was measured on bagged twigs with. a pressure probe (PMS), repeatable to better than 0.05 MPa An eight channel dielectric monitoring system (DMS) waa used to monitor L-band dielectric constant within the tree xylem. Probe. tips were inserted 5 mm into the hydroactive xylem. The DMS is an Applied Microwave Field Portable Dielectric Probe, interfaced to an eight channel switching unit and a data logger (Delta-T) [3]. It permits independent monitoring of eight different locations. Each channel incorporates two coaxial tips, with one tip inserted into the hydroactive xylem region of the tree bole and one tip measuring dry air as a calibration reference. Thii permits immolate compensation of system drifts caused by variations in air and cable temperature. A full DMS measurement cycle on 8 trees was completed every eight minutes.

RESULTS AND DISCUSSION

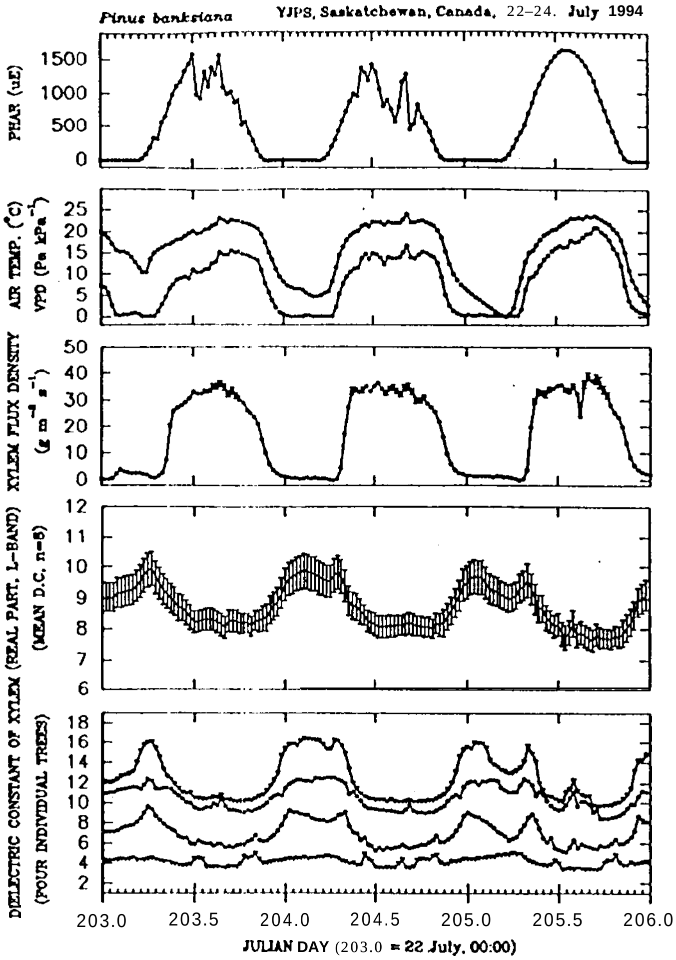
During the observation period in mid to late summer JD 209 had the highest half hourly PAR of 1.7 mmol m^{-2} s^{-1} and JD 247 the lowest with 0.3 mmol m^{-2} s^{-1}, while peak PAR on clear days decreased by 7 µmol m^{-2} s-' day^{-1}. TA ranged from 32 “C to -3 “C with the first frost occurring on JD 206 and night TA below O °C on 21 days. Very high VPD occurred throughout the observation time e.g. 34 Pa kPa^{-1} (JD 227) and 33 Pa kPa^{-1} (JD 262). TS did not exceed a amplitude of 8 °C day-* and varied from 22 to 7 ‘C. The largest rain event was >120 mm from JD 199-201.

Xylem Dielectric Constant

Fig. 1 shows PAR (top), air temperature and VPD (second from top), XFD (third from top), mean XDC of eight trees (second from bottom, error bars indicate standard error), and XDC of four selected individual trees. Mean XDC changed significantly from day to nighttime. Absolute values of dielectric constant were generally low and diurnal amplitude was comparably small (approx. 7 to 11 during July). Lowest values were observed from midday until late evenings with highest values briefly past midnight and before sunrise. The double peak at night was inconsistent with observed tree water potential or water content changes. Fig. 2 shows that mean XDC did not change significantly with a wide range of xylem temperature, but a trend of higher values is occurring around 5 to 10 “C. Mean XDC showed a decrease with higher VPD and XFD, but the trend was not significant. Individual trees varied widely in trend and diurnal amplitude of XDC changes (Fig. 1, bottom). This was also found in previous studies in Alaska [4]. The variability was not explained by variation in tree size and canopy exposition and was not correlated with measured water potential changes. In individual trees the correlation between XDC, micro-meteorological parameters, tree water status and XFD was weak. Changes of XDC were observed during short term manipulation of water potential while tree water content did not change significantly indicating a decoupling of XDC from environmental parameters. XFD in trees was linearly related to the xylem water potential gradient. Tree. hydraulic conductance was weakly correlated with xylem water potential and VPD. No significant relationship was found between tree water potential and water content.

Xylem flux and water consumption

Peak XFD ranged from 42 g $m^{-2}s^{-1}$ (largest measured tree) to 58 g $m^{-2}s^{-1}$ (smallest tree). Differences in XFD between individual trees were generally much smaller and diurnal trends in all trees were similar. This can be explained by the open stand structure where all individuals independent of size were well exposed to PAR and atmospheric mixing. Daily max. XFD did not follow a clear seasonal trend and, after a pronounced decline during rainless periods to 2-5 g $m^{-2}s^{-1}$, it recovered on JD 248 within one day after rainfall to more than 50% of the maximum. Stand transpiration (E) was calculated from eight trees using XFD and the mean stand sapwood area. Fig. 3 shows the daily sum of transpiration for the entire observation period (1659= JD 198 = 17. July). Maximum E was 2.1 mm d^{-1}, and the minimum 0.2 mm d*. During the longest rain event (JD 199-201), xylem flux at the tree base continued for two consecutive nights in spite of very low VPD. From JD 199-202 approx. 1.3 mm of water were added to the canopy storage, which in general is limited by the small volume of



Fig, 1: Photosynthetic active radiation (top), mid-canopy air temperature and vapor pressure deficit (second from top), xylem sap flux density (third from top), mean xylem dielectric constant of eight trees (second from bottom, error bars indicate standard error), and xylem dielectric constant of four selected individuals of ***Pinus banksiana*** *in* a young uniform stand for three days (22.-24. July).

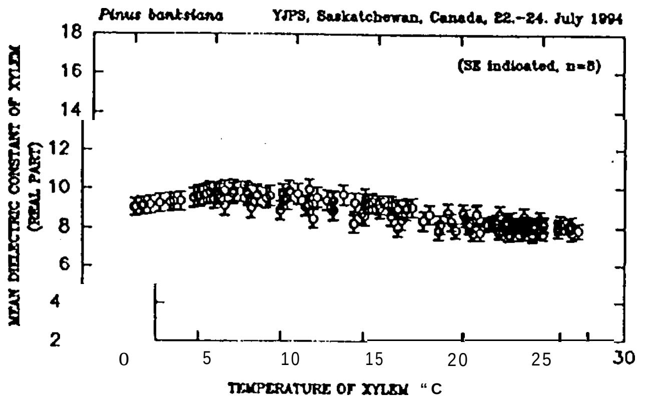


Fig.2: Mean xylem dielectric constant of ***P. banksiana*** for three 24 hour periods in July over a wide range of xylem temperature. Horizontal (n=3) and vertical (n=8) error bars are indicated.

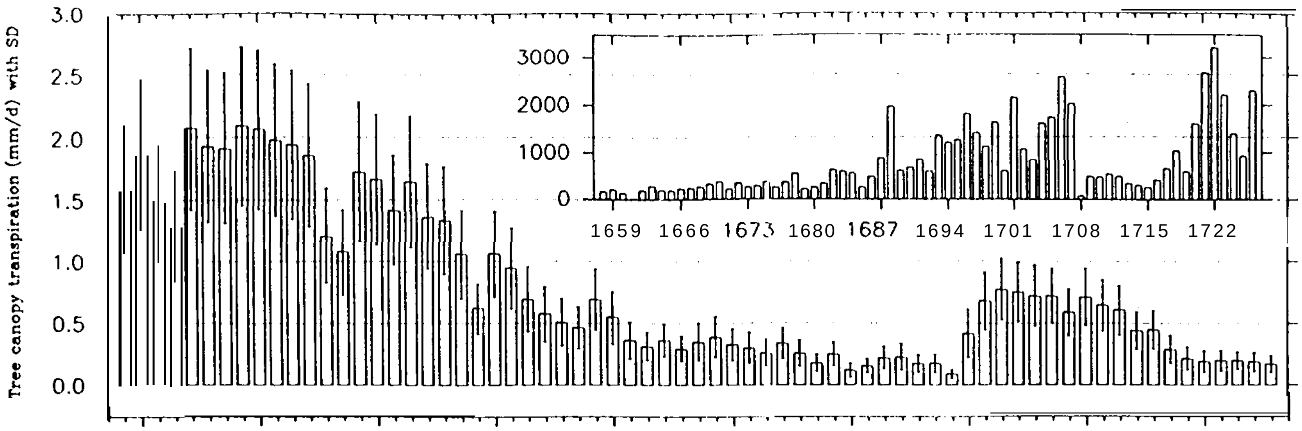


Fig.3: Daily sum of tree transpiration for a young stand *of Pinus banksiana in* Saskatchewan, Canada from 16. July to 22. September 1994. **The** small **box** (top right) shows the **daily** half-hourly, cumulative **VPD** vs. daily sum of E.

the stems, branches and needles. This was also observed **after** rain on **JD** ***247-248 with 0.4 mm tree*** recharge. Since tree storage supports only **approx.** one day of high E, root **access** to soil water is more important. Few days **after** soil water recharge by **rain,** max. XFD and daily sum of E declined rapidly and **showed** no longer a relationship **with** cumulative VPD or cumulative PAR. The **small** inset box (top right) in Fig. 3 demonstrates this decoupling, showing daily cumulative VPD vs. daily sum of E (note e.g. for the last few observation days). Fig. 4 **shows** the daily sum of E, plotted against the cumulative E starting **from** soil saturation by rain and

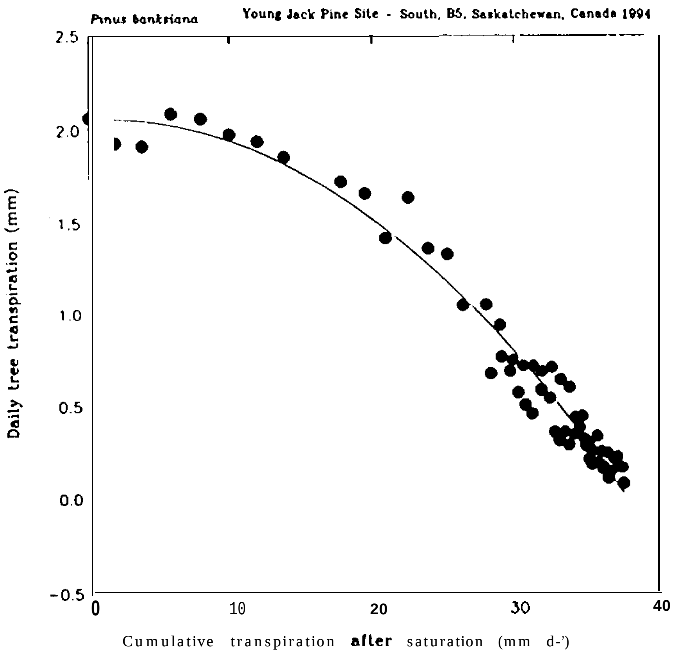


Fig.4: Daily sum of transpiration vs. the cumulative transpiration (starting **from** day **201** when high soil water storage was reached).

adjusted for recharge by rain Note that the individual points in Fig. 4 do not simply represent a time series. Daily sum of E decreased independent of meteorological conditions, following the decrease in available soil water. Tree water consumption **from JD** 197-265 was S4.8 nun (0.81 mm d^{-1}) with more than 50 % **consumed in the first two weeks when soil water storage was high.**

CONCLUSIONS

Mean xylem dielectric constant of eight trees changed significantly **from** day to nighttime, while individual trees varied widely in trend and diurnal amplitude of xylem dielectric constant. Seasonal stand transpiration was primarily depending on soil water availability, which **was** reflected in a decreasing daily transpiration during periods of water storage depletion.

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